FLEXIBLE MULTI-GROUP SINGLE CARRIER MODULATION: OPTIMAL SUBCARRIER GROUPING AND RATE MAXIMIZATION

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KEY OBJECTIVE

To propose a new modulation scheme that is able to improve the rate-PAPR trade-off over OFDM and SC-FDE, i.e., achieve high data rate at low PAPR.

1. INTRODUCTION

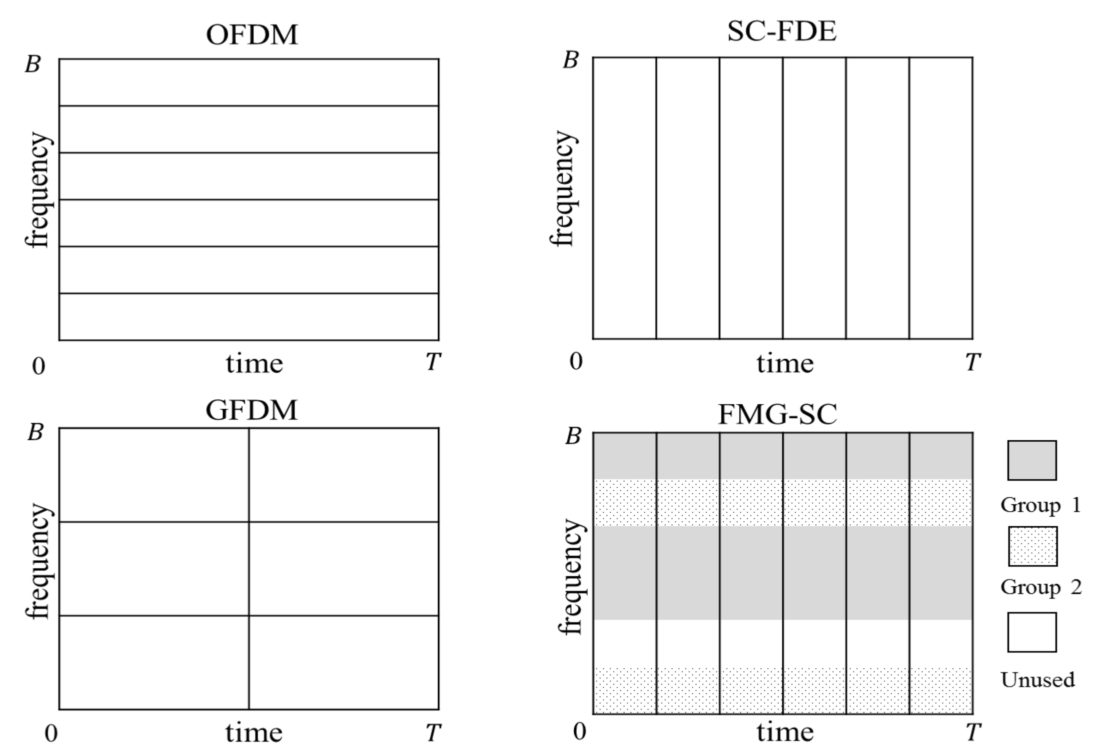
Multicarrier modulation is a promising technique to meet the growing demand for higher data rate and provide enhanced immunity against multipath interferences in broadband communications over frequency-selective channels.

Existing techniques:

- **OFDM**: flexibility for channel-adaptive bit and/or power loading for performance optimization [1]. High data rate but also high PAPR [2]. PAPR reduction techniques lead to higher implementation complexity.
- **SC-FDE:** low PAPR but also low data rate. Optimal power loading at cost of higher PAPR [3].
- **GFDM:** non-orthogonality leads to interference and higher implementation complexity [4].

Proposed new modulation scheme

- **FMG-SC**: **Flexible Multi-Group Single Carrier** modulation. Specifically, the total number of subcarriers $\boldsymbol{N}$ is flexibly divided into $\boldsymbol{K}$ orthogonal groups based on their channel gains, where these groups apply SC-FDE to send different data streams in parallel.



5. CONCLUSIONS

- Proposes a new general modulation scheme termed FMG-SC for broadband communication over frequency-selective channels, which encapsulates conventional OFDM and SC-FDE modulations as special cases.
- Studies the optimal subcarrier grouping for FMG-SC to maximize the achievable rate, and propose two low-complexity methods that can find nearly optimal solutions efficiently.
- More practically favorable rate-PAPR trade-offs over existing OFDM and SC-FDE, shown by simulations.

REFERENCES

[1] A. Goldsmith, *Wireless Communications*. Cambridge University Press, 2005.

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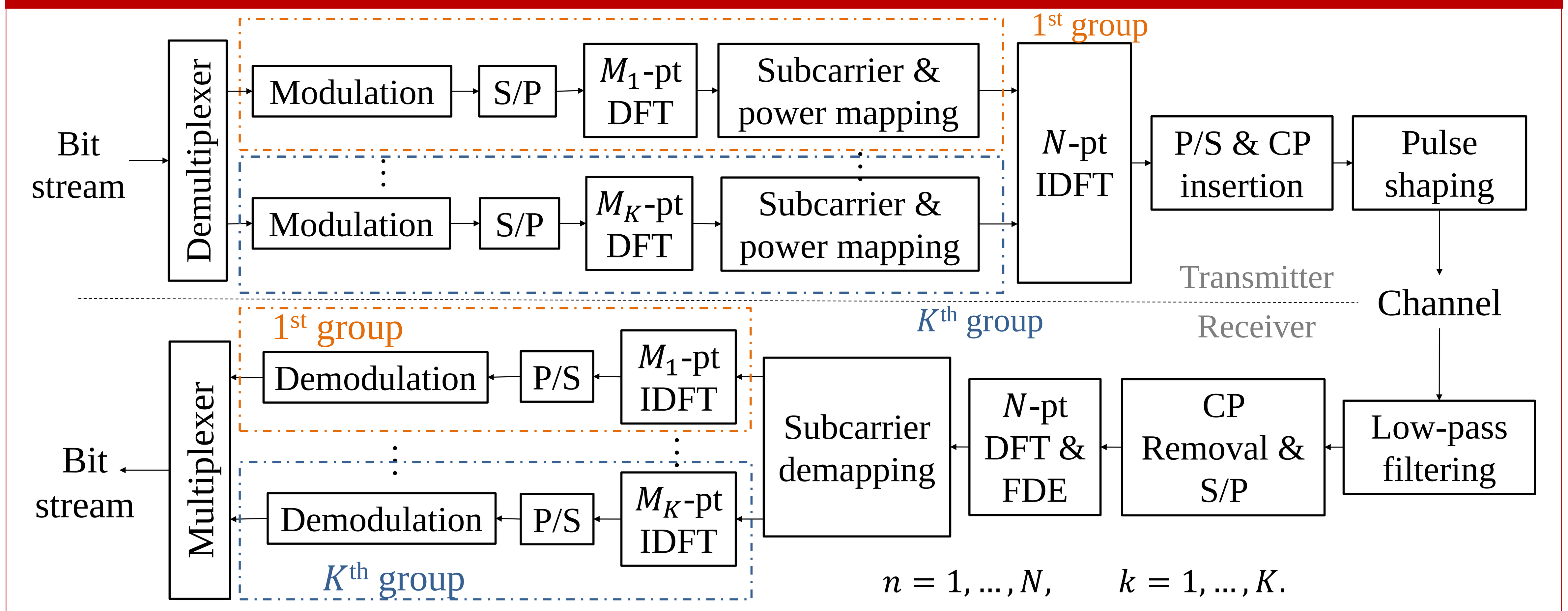
2. SYSTEM MODEL



$n = 1, \dots, N, \qquad k = 1, \dots, K.$

$\alpha_{k,n}$: subcarrier-group mapping indicator.
M_k: number of subcarriers assigned to group k.
h_n: channel frequency response at subcarrier n.
γ_k: receive SINR for group k.
σ^2: baseband CSCG receive noise variance.
R_k: maximum achievable rate of group k.
Γ : SNR gap to Shannon capacity

$$\alpha_{k,n} = \begin{cases} 1, \text{if subcarrier } n \text{ is assigned to group } k, \\ 0, \text{otherwise.} \end{cases}$$

$$\sum_{n=1}^{N} \alpha_{k,n} = M_k.$$

$$\gamma_k(\{\alpha_{k,n}\}) = \frac{1}{\frac{1}{M_k}\sum_{n=1}^{N} \alpha_{k,n}\left(\frac{\sigma^2}{\sigma^2 + |h_n|^2 p_k}\right)} - 1$$

$$R_k(\{\alpha_{k,n}\}) = \frac{M_k}{N}\log_2\left(1 + \frac{\gamma_k(\{\alpha_{k,n}\})}{\Gamma}\right)$$

Note that equal power allocation in all used subcarriers is assumed, i.e. power allocated to each subcarrier in group k, $p_k = P/\sum_{k=1}^{K} M_k$, where P is the total transmission power. We also assume it is possible that a subcarrier may not be assigned to any group, i.e. remains unused.

3. PROBLEM FORMULATION AND PROPOSED SOLUTIONS

$$\text{(P1)}: \underset{\{\alpha_{k,n}\}}{\text{maximize}} \sum_{k=1}^{K} R_k(\{\alpha_{k,n}\})$$

$$\text{subject to } \alpha_{k,n} \in \{0,1\}, n = 1, \dots, N, k = 1, \dots, K,$$

$$\sum_{k=1}^{K} \alpha_{k,n} \le 1, n = 1, \dots, N,$$

$$\sum_{n=1}^{N} \alpha_{k,n} \ge 1, k = 1, \dots, K.$$

- P1 is a non-convex combinatorial optimization problem due to the binary constraint on $\alpha_{k,n}$.
- Exhaustive search over all possible mappings for the highest achievable rate has complexity $\mathcal{O}(NK(K+1)^N)$.

Solution 1: **Set Partitioning Optimal Search (SPOS)**

- $(1+\gamma_k)$ is the harmonic mean of $\left(1 + \frac{p_k |h_n|^2}{\sigma^2}\right)$ for all subcarrier n that belongs to group k.
- Harmonic mean operation is known to be dominated by the smallest elements in the arguments. Intuitively, subcarriers with similar SNR values should be grouped together.
- Solve by considering the problem of finding the optimal partition of N subcarriers sorted in an increasing order of their SNRS into $K+1$ non-overlapping groups to maximize sum-rate.
- Optimal result obtained by exhaustively search over all possible set partitioning.
- Complexity: $\mathcal{O}(N\log N + N^{K+1})$.

Solution 2: **Set Partitioning Gradient Search (SPGS)**

- Make an initial guess of the group boundaries to the method in SPOS, e.g., equal partition.
- Move each boundary by at most one position to the direction that maximize the sum-rate in each inner iteration, complete for all boundaries for one outer iteration.
- Iteration stops when no movement in one outer iteration.
- Complexity: $\mathcal{O}(N\log N + N^2K^2)$.

4. SIMULATION RESULTS

- We consider a Rayleigh fading channel with 8 taps and 64 subcarriers. MQAM modulation with bit granularity of 1/3 and root-raised cosine pulse shaping function with roll-off factor 0.1 are considered.
- We show the optimality of the proposed algorithms SPOS and SPGS by comparing with exhaustive search (ES), equal-partition on unsorted subcarriers (EP-US) and on sorted subcarriers (EP-SS). The superiority of the proposed modulation is shown by comparing its achievable rate and mean PAPR with WF-OFDM and SC-FDE.